53/P

JUNE, 1919 MEMOIR 26

CORNELL UNIVERSITY

AGRICULTURAL EXPERIMENT STATION

THE DRY ROOT-ROT OF THE BEAN

WALTER H. BURKHOLDER

1 JUL 1921 OF MYCOLOGY

ITHACA, NEW YORK
PUBLISHED BY THE UNIVERSITY

JUNE, 1919 MEMOIR 26

CORNELL UNIVERSITY
AGRICULTURAL EXPERIMENT STATION

THE DRY ROOT-ROT OF THE BEAN

WALTER H. BURKHOLDER

ITHACA, NEW YORK
PUBLISHED BY THE UNIVERSITY

CONTENTS

PAGE

Symptoms of the disease 1004
On the roots and other underground parts 1004
On the plant above ground 1005
Symptoms of other root diseases of the bean 1006
Black root-rot 1006
Rhizoctonia blotch 1007
Etiology 1007
Morphology 1007
Cultural characters 1008
Nomenclature 1010
Life history 1012
Pathogenicity 1017
Inoculation experiments with the bean plant 1017
Cross-inoculations 1019
Effect of weather conditions 1019
Effect of dry root-rot on the yield of the bean crop 1022
Control 1027
Rotation of crops 1027
Soil treatment 1028
Use of beans resistant to root-rot 1030
Literature cited 1032

THE DRY ROOT-ROT OF THE BEAN

THE DRY ROOT-ROT OF THE BEAN

WALTER H. BURKHOLDER [1]

Very little consideration has been given to the diseases that affect the bean plant (*Phaseolus vulgaris* L.) below ground. During the past few seasons an investigation of bean diseases in New York State by the writer has shown that such diseases are very common and frequently very destructive. The most important of these, and one that is enphytotic to the western bean section of the State, is the dry root-rot. This disease affects all the commercial varieties of the dry shell beans, and, so far as known, all those used for canning purposes. The dry root-rot may occur also on other species of Phaseolus. The following are affected: the tepary bean (*P. acutifolius* Gray var. *latifolius* Freeman), the scarlet runner bean (*P. multiflorus* Willd.), the moth bean (*P. aconitifolius* Jacq.), the lima bean (*P. lunatus* L.), and the adzuki bean (*P. angularis* Willd.). The disease has likewise been observed on the Black-eye cowpea (*Vigna sinensis* [L.] Endl.) and the kulti bean (*Dolichos biflorus* L.).

In New York State the disease is of general occurrence. It has been observed in 90 per cent of the bean fields of the six largest bean-producing counties, and is found wherever the crop has been grown to any extent. Specimens of bean plants affected with the dry root-rot have been received from A. H. Gilbert and G. A. Meckstroth, of the United States Bureau of Plant Industry, collected at Burlington, Vermont, and Grand Rapids, Michigan, respectively.

It is not known when the dry root-rot first appeared in New York State. A few growers claim to have observed it for at least twenty-five years. Since it is now of such general distribution in the bean sections, apparently it must have been present for a long time. As far as known, no reference to this disease has ever been made in literature except by the writer (1916 and 1917), and these references apply to New York State. The disease therefore evidently originated in this region or was introduced from a locality where it has not attracted attention. The symptoms of the disease above ground are not striking and could readily be mistaken

[1] The writer wishes to acknowledge his indebtedness to Dr. Donald Reddick for helpful suggestions and criticisms during the progress of this work.

for the result of unfavorable weather conditions. Thus, where the disease is not abundant it could easily be overlooked.

In New York State where the dry root-rot is common, severe losses to the bean crop result. It is a matter of common observation that there has been during the past ten years a marked decrease in the bean yield. The decrease has been estimated by a number of the large growers and seedsmen to be approximately 25 per cent. The writer, from observations in the bean section, is led to the conclusion that no small part of this decrease is due to the dry root-rot.

SYMPTOMS OF THE DISEASE

ON THE ROOTS AND OTHER UNDERGROUND PARTS

The first signs of the disease on the bean show a week or two after the plant has appeared above ground. At this time there may be observed

FIG. 133. THE DRY ROOT-ROT OF THE BEAN

At left, root of a White Marrow bean affected with dry root-rot. At right, a healthy root; the strong lateral roots branching off from the lower end of the taproot are evident

on the taproot a reddish discoloration, but the morphology of the root remains normal. The discoloration may cover the taproot and have no

DRY ROOT-ROT OF BEAN

1, A field of White Marrow beans affected with dry root-rot. The rows are 28 inches apart. Healthy plants would cover the ground

2, The dry root-rot of the bean. A mass of surface roots has been produced above the dried taproot

3, Flat Marrow bean resistant to dry root-rot. The effect of the disease is shown on the White Marrows near the Flat Marrow

EFFECT OF DRY ROOT-ROT ON THE PARTS OF THE WHITE MARROW BEAN PLANT ABOVE GROUND

The diseased plant has failed to vine. Also the pods are few in number and are poorly filled

definite margin, or may occur as red streaks which frequently extend to or above the surface of the ground. Later the diseased areas become brown and longitudinal fissures appear in the cortex.

As the disease progresses upward, the lower lateral roots and the end of the taproot shrivel and become dry. Frequently, too, the main root and the lower part of the stalk are found to be pithy. Above the dead area new lateral roots are developed. These frequently push their way through the diseased cortex and subsequently become diseased. Other roots that are produced above the lesions may develop rapidly and become abnormally large, to take the place of the diseased lower rootlets. Occasionally one of these lateral roots takes the place of the taproot. More frequently, however, these surface roots are small and very numerous, and form a dense mat in the first inch or so of soil (Plate LVI, 2). As a rule they do not become severely affected, and persist throughout the entire growing season. On the other hand, in severe cases the entire root system may be destroyed.

ON THE PLANT ABOVE GROUND

Although no lesions appear above ground, the effect of the loss of the lower lateral roots and part of the taproot is very noticeable. This is especially true during the latter part of the growing season. During the first five to six weeks of growth a diseased plant may not be readily detected unless in comparison with a healthy one. At this stage the affected plant is slightly dwarfed but otherwise remains normal in appearance so far as the parts above ground are concerned. The symptoms of the disease are more evident at podding time. There is then an apparent checking in growth of the entire plant. Few pods are formed, and the remainder either fail to set, or drop in the early stages of their formation (Plate LVII). The leaves of plants affected with the dry root-rot frequently turn yellow and fall. This has given rise in some localities to the name *yellow-leaf*, but it is a character which is not constant. Nevertheless, the diseased individuals mature earlier than do normal plants, since they dry much more rapidly in the absence of an entire root system. The seeds also in the few pods frequently are under size, and this contributes to the loss in yield.

In the true sense of the word this disease is not a wilt, as the leaves or the tender parts of the plant seldom flag. In a few cases, however,

the writer has observed a distinct wilting of the plants. In these latter cases all the leaves dropped and turned brown, and persisted on the plant. The small pods withered and clung to the stem, while the older pods matured a few small seeds. A condition similar to this has frequently been observed which is due to the bacterial blight caused by *Bacterium phaseoli* E. F. Smith. Careful examination, however, may distinguish between the two diseases.

The general appearance of fields of beans affected with the dry root-rot may vary. Whenever the disease occurs in a field, approximately 100 per cent of the plants show the symptoms. All the plants may appear uniform (Plate LVI, 1); on the other hand, certain parts of the field frequently are affected more severely than others, thus giving the appearance that the disease occurs in limited areas. There are several possible explanations for this spotted condition. One is that the soil conditions are not uniform; a second is that frequently wireworms or other insects attack the decaying roots and complete their destruction.

SYMPTOMS OF OTHER ROOT DISEASES OF THE BEAN

Two other root diseases of the bean in New York State might be confused with the dry root-rot. They are the black root-rot, caused by *Thielavia basicola* Zopf., and a blotch caused by Rhizoctonia. In the greenhouse, species of Botrytis, Fusarium, and various other fungi attack the young seedling at the surface of the ground or cause more or less of a root disturbance. These fungi have seldom been observed in the field.

Black root-rot

The black root-rot in New York State is local in its distribution. It has been observed only along the southern edge of the dry-shell-bean district. In its early stages this disease is scarcely distinguishable from the dry root-rot. The discoloration of the taproot at times may appear to be somewhat purple in contrast to the orange-red color produced by the dry root-rot. Otherwise the two diseases are very similar. Later in the season, coal-black lesions, which are very characteristic, appear on the affected roots. These lesions may vary from small streaks to cankers which encircle half the taproot and completely envelop many of the lateral roots. Frequently during damp weather a frosty appearance may

be noticed over the lesions and the diseased parts of the plants. This is due to the large production of the so-called endoconidiophores belonging to *Thielavia basicola*. Since this disease is often observed associated with the dry root-rot, the two groups of symptoms may be found together.

It has been the observation of the writer that the black root-rot occurs more generally during the early part of the growing season, and at times affects germination. Frequently plants affected with this disease may be able to throw it off by the middle of August, and late infection causes no serious injury to the root system. These two observations have been further substantiated by the writer through inoculation experiments. The symptom of the dry root-rot, on the other hand, is more evident during the latter part of the season.

Rhizoctonia blotch

The Rhizoctonia blotch in New York State is of general distribution but has never been observed to cause any appreciable losses. Brick-red blotches are produced mainly on the taproot and on the bean stem near the surface of the ground. The lateral roots are seldom affected. The lesions caused by Rhizoctonia are sunken, and usually irregular but definite in outline. This is the most distinguishing characteristic of the disease, and as a rule readily separates it from the other root diseases of the bean.

ETIOLOGY

The dry root-rot disease of the bean is caused by the fungous pathogene *Fusarium martii phaseoli* n. form.

MORPHOLOGY

The pathogene causing dry root-rot of the bean has the following morphological characters:

Macroconidia mostly 3-septate (44.5 x 5.1 μ), 4-septate (50.09 x 5.3 μ), rarely 5-septate, of nearly even diameter throughout, more or less curved near apex, with somewhat rounded or but slightly pointed apex, usually apedicellate. Microconidia rare. Aerial mycelium in culture scanty and usually white. Spores borne mostly in pseudopionnotes. Cultures when mature from a lichen[2] and montpellier green (on synthetic agar [3])

[2] The colors are after Robert Ridgway's *Color Standards and Color Nomenclature.*
[3] Richard's solution with two per cent agar.

to a pale olive-buff or cinnabar-green (on potato agar), to a zinc-green and dusky green-blue (on potato plug), to a purple-drab (on steamed rice). Spores in mass frequently yellowish. Chlamydospores terminal or intercalary, single or in short chains (11.6 μ in diameter).

CULTURAL CHARACTERS

In growing the fungus on various media, a marked variation in its microscopical appearance is seldom found. The intensity of color production, however, varies considerably, not only on different media but on the same medium with the presence or the absence of air. The colors, when produced, are of various shades of blue and green. The spore mass frequently has a yellowish appearance. The growth of *Fusarium martii phaseoli* on steamed rice differs greatly from that on any other medium used. The fungus on rice is purple-drab but the medium itself is colored a coral pink. Microscopically also there is a great change. The spores are very abnormal and a great number of microconidia are produced. On cellulose agar the fungous growth is very scanty and there is scarcely any digestion of the cellulose.

The proportion of conidium types (those bearing the same septations) and the conidium measurements do not vary greatly on the different agars and on sterilized vegetables. For making the measurements, the fungus was grown on six different media. In the majority of cases the media were the same as those used by Sherbakoff (1915 b) in his study of *Fusarium martii* Ap. and Wr. The age of the cultures also was similar; in most cases they were in a state of maturity. One hundred conidia taken at random were measured in each case. Types that occurred in a culture but were not found when measuring the spores were marked "rare." It was considered that such types were present in less than one per cent.

The measurements of the conidia were as follows:

On bean plugs, cultures eighty-three days old; conidia taken from pseudopionnotes:

Conidia: 3–septate, 38 per cent, 41.4 x 4.9 (37.7–46.5 x 3.9–5.8) μ
4–septate, 62 per cent, 47 x 5 (40.3–53.3 x 4.5–5.8) μ
5–septate, rare

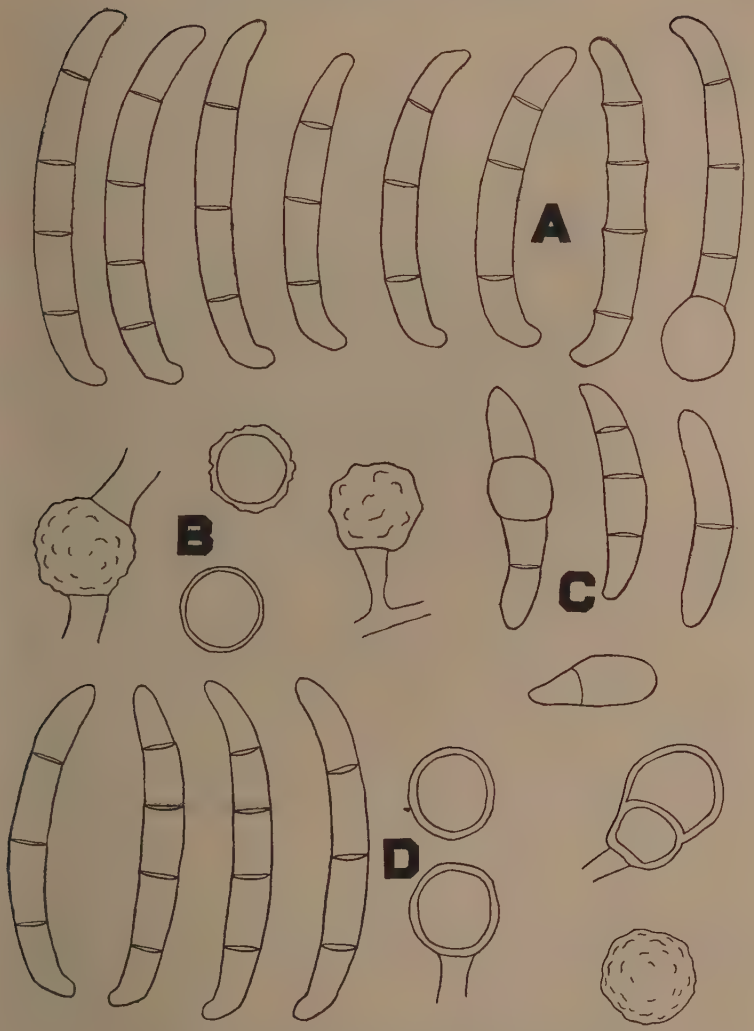

FIG. 134. SPORES OF FUSARIUM MARTII PHASEOLI

A, Macroconidia from sterilized bean plug cultures 83 days old; B, chlamydospores from the same culture; C, macroconidia from steamed rice, cultures 80 days old; D, macroconidia and chlamydospores from potato agar cultures 70 days old. Camera lucida drawings, × 1027

On raspberry cane plugs, cultures eighty days old; conidia taken from pseudopionnotes:

Conidia: 2–septate, rare
3–septate, 66 per cent, 41.4 x 5 (32–48 x 4–5.8) μ
4–septate, 34 per cent, 49.3 x 5 (44–56 x 4–5.8) μ

On potato agar containing one per cent glucose, cultures twenty-two days old; conidia from pseudopionnotes:

Conidia: 2–septate, 3 per cent, 37.7 x 4.4 (36–40 x 4–5.3) μ
3–septate, 83 per cent, 43.5 x 5.2 (33.3–56 x 4–6.6) μ
4–septate, 14 per cent, 52.3 x 5.4 (42.6–60 x 4.6–6.6) μ

On slightly acidified hard potato agar, cultures eleven days old; conidia from pseudopionnotes:

Conidia: 3–septate, 24 per cent, 48.7 x 5.3 (35.3–53.3 x 4.6–6.6) μ
4–septate, 76 per cent, 52.9 x 5.5 (46.6–56 x 4.6–8) μ
5–septate, rare

On potato plug, cultures eighty-three days old; conidia from pseudopionnotes:

Conidia: 2–septate, rare
3–septate, 76 per cent, 43.5 x 5.2 (36–48 x 4–8) μ
4–septate, 24 per cent, 46 x 5.5 (42–49.3 x 4.6–6.6) μ

On synthetic agar,[4] cultures thirty-three days old; conidia from pseudopionnotes:

Conidia: 3–septate, 24 per cent, 50.7 x 5.1 (41.6–58.5 x 4.5–6.5) μ
4–septate, 76 per cent, 54 x 5.2 (29.9–59.8 x 3.9–6.5) μ
5–septate, rare

NOMENCLATURE

The name *Fusarium martii* was first used by Appel and Wollenweber (1913) to describe a fungus which they regarded as identical with *Fusisporium solani* Martius. These investigators presented a detailed description of the species, as did also Sherbakoff (1915 b) a few years later in his monograph on the Fusaria of potatoes. In both instances the fungus

[4] Richard's solution with two per cent agar.

was found on decaying potato tubers and was considered to be saprophytic on that host. On the other hand, Carpenter (1915) refers to a culture of *Fusarium martii* isolated from *Pisum sativum* by Westerdijk and determined by Wollenweber, which evidently was considered to be parasitic since it was thought by Miss Westerdijk to be *F. vasinfectum* var. *pisi* Van Hall, the cause of the St. John's sickness of garden peas. So far as is known, no inoculation experiments were made. Wollenweber shows drawings of this strain in *Fusaria autographia delineata*, issued in 1916.

The fungus isolated from diseased bean roots, and proved to be parasitic on this host, is practically identical with *F. martii*. The spore measurements are approximately the same. The color production is identical with that of *F. martii* and the pathogene in appearance agrees remarkably well with the plates given by Carpenter (1915). The number of septa in the conidia, and the proportion of conidia having the same number, also are similar. One slight difference was observed. Appel and Wollenweber state that 5-septate spores are rare, but they find a sufficient number to give spore measurements and drawings. Sherbakoff likewise finds as many as seven per cent of 5-septate spores on some media. In the species under consideration, 5-septate spores were found in less than one per cent. The fact that they occur in fewer numbers, however, seems of small consequence and can scarcely be pointed to as a distinct difference in the two organisms. Moreover, a culture of the fungus from affected bean roots was sent for determination to Dr. Sherbakoff, who states, in a letter to the writer, that this fungus "is morphologically the same as *F. martii* because of the same macroscopical characters, the same type and size of conidia and of the same chlamydospores." Slight differences that might occur he considers not sufficient to separate this fungus from the above species.

For comparison of the fungus under consideration with *F. martii*, cultures of the latter were obtained at various times from several different sources. The first culture received was from R. J. Haskell and was originally from Dr. Sherbakoff, the latter having discarded his own cultures; a second culture was supplied by the Bureau of Plant Industry from Wollenweber's collection; a third was from J. Westerdijk at the Centralstelle für Pilzkulturen. The macroscopical appearance of subcultures from these were slightly different from the organism from bean root. There was also a slight difference in appearance among the three

strains of *F. martii*. The difference lay in intensity of color, greater or less amount of aerial mycelium, and variations in the formation of pseudopionnotes. Spore measurements made from the culture obtained from the Wollenweber collection varied considerably from the measurements given by Appel and Wollenweber and by Sherbakoff. The cultures from the Centralstelle für Pilzkulturen, however, agreed very closely with the original measurements. Unfortunately the strain isolated from potato by Dr. Sherbakoff was lost before spore measurements could be made. Inoculation experiments, however, were conducted with all three strains with the bean as the host plant. In no case did infection occur. It is very improbable that these negative results are due to unfavorable conditions, as positive results were always obtained at the same time with the fungus from bean roots. There is no evidence that *F. martii* is parasitic on the bean root.

From the foregoing statements it seems scarcely possible that the bean Fusarium is identical with *F. martii*. There is a distinct physiological difference, and possibly slight morphological differences. The latter are so unimportant that the writer does not feel justified in using them as the basis of a new species or even a new variety. Physiological differences, however, have been used in this genus as the basis of new varieties. *Fusarium vasinfectum* var. *inodoratum* Wr. differs from *F. vasinfectum* Atk. only by the absence of odor. On the other hand, in other groups it has been the custom, when the physiological difference was one of pathogenicity, to treat the new form as a biologic species. For this reason the writer has used the trinomial *Fusarium martii phaseoli*.

Since one strain of *F. martii* was isolated from a diseased pea root by Dr. Westerdijk, there is the probability of another biologic species, *F. martii pisi*. The writer, however, obtained no infections on the garden pea when inoculations were made with *F. martii*. The original species appears to be saprophytic.

LIFE HISTORY

The time of bean planting in New York State varies according to weather conditions, but usually the seed is put into the ground in the first half of June. The soil at that time is in a warm and moist condition. Thus as soon as germination of the bean seed takes place, external factors are favorable for the infection of the young roots by the dry

root-rot fungus. The taproot, being the first to develop, soon shows symptoms of the disease. This is frequently a week or two after the host plant is above ground. It has been determined by experiment that further infections may take place at any time during the growing season of the bean plant.

The exact mode of infection is not known. The fungus, however, may penetrate the healthy epidermis. After the mycelium has once

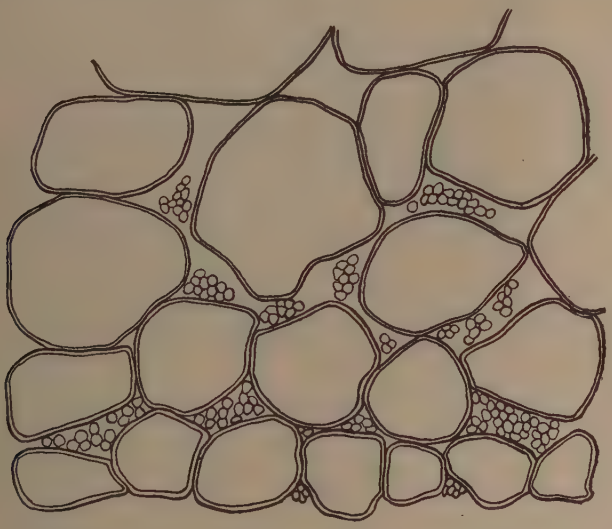

FIG. 135. CROSS SECTION OF THE CORTEX AND EPIDERMIS OF THE TAPROOT OF A BEAN AFFECTED WITH DRY ROOT-ROT

An early stage in the progress of the disease, showing the intercellular and parallel hyphae. Camera lucida drawing, × 514

gained entrance to the host, it is for a short time intercellular in the cortical tissue. In the main the hyphae are found extending longitudinally with the taproot. Occasionally as many as a dozen hyphae may be observed growing parallel in the intercellular spaces (fig. 135). This tendency on the part of the fungus to form rhizomorph-like structures is further developed on the outside of the host, where strands 75 μ in diameter frequently occur over the diseased areas. Likewise, in culture,

Fusarium martii phaseoli produces these strands, which at times develop into coremium-like structures of fructification.

The mycelium in the host rarely extends any distance above the surface of the soil. In its growth in the cortex it possibly reaches its greatest height; here, at times, the coloration due to the fungus may appear on the lower part of the stem. The mycelium in the cortex of the upper part of the root does not penetrate into the vascular bundles, hyphae having been observed to enter the vascular system only through the small lateral rootlets on the lower part of the taproot. The mycelium does not long remain intercellular, but soon enters the cells of all the tissue. From the lower part of the taproot the hyphae progress upward through the cells of the vascular system. Frequently they fill these cells or cause them to collapse, but seldom is a wilting of the host plant produced. The growth of the fungus is extremely slow; by harvest time of the host it frequently has not reached within an inch of the surface of the soil. The height that it attains in the vascular tissue, however, depends on the time of infection.

F. martii phaseoli produces two kinds of spores on and in the bean roots. They are the chlamydospores and the conidia of the fungus. The chlamydospores are borne singly, or, less frequently, in small chains within the host tissue. For the most part they are found in the cortex. In the smaller fiber-like rootlets they occur in greater numbers than in the larger lateral roots and in the taproot. This is due probably to an absence of sufficient food material in the smaller roots. Repeated attempts to germinate these spores have failed. Evidently the optimum set of conditions governing germination has not been discovered. Conidia are rarely produced in abundance on the host during the growing season. Frequently spores cannot be found even on severely diseased roots. Before the cause of the dry root-rot was determined, many specimens of infected bean roots were examined without success in finding the spores of the causal organism. A few instances only have been observed of large production of conidia on the dead parts of affected roots. Such cases were during rainy weather, and then the production was so great that the roots appeared whitish. Apparently a sufficient number are always produced for the dissemination of the fungus. In many of the infested fields a small quantity of soil will contain the pathogene to such

an extent as to cause immediate infection of bean seedlings. This, however, might be due to the mycelium.

From observations it appears that as a rule the fungus is disseminated in the manure used to fertilize the bean fields. It is the practice of growers to pull the bean plants in the late summer, and, after threshing the seed, to use the remainder of the plant as bean straw. This is fed to cattle and sheep and is one of the valuable by-products of the bean industry. The straw contains the diseased bean roots, which are seldom eaten but are thrown into the compost heap where they undergo further decomposition. The fungus here lives saprophytically and produces its spores on old bean roots and stems. When the manure is spread over the fields the pathogene also is carried to new areas. A striking instance of this was observed on a farm near Perry, New York. During the latter part of the growing season of 1916, the location could be determined where four loads of manure had been distributed in the bean field. This was due to the fact that the dry root-rot was more severe in these places.

In the sections where snap beans are grown, this method of dissemination of the fungus does not apply. Here, after the crop is harvested, the vines are plowed under, not pulled for straw. Thus the fungus does not get into the manure, and therefore is not distributed so readily over the fields.

The pathogene may be carried from one field to another in various other ways. It may be disseminated on the feet of horses and of men, and on tillage instruments. It may be spread by the wind, blowing dust from field to field. Observations in the greenhouse indicate that it can be carried by insects. Another means of dissemination is by washing. In the valleys about Warsaw and Attica, New York, all the fields are equally contaminated with *F. martii phaseoli*, whether or not they have been planted to beans or have had bean-straw manure applied to them. It is known, however, that in certain years these fields have been under water during the early spring. At such periods it is very probable that the pathogene is carried from field to field along the valleys.

There are no indications that the fungus is carried with the seed, although if the seed is not well cleaned it may harbor small pieces of the diseased roots and particles of dirt containing the pathogene.

The dry root-rot fungus may overwinter in the bean straw or in the compost heap, and in the following spring it is returned to the fields.

This is a common method of hibernation, but it does not account for the presence of the fungus in the majority of fields in the bean section of New York State. The pathogene when it once gains entrance into a field is very persistent, and may live for a number of years as a saprophyte in the soil. Since the common practice in the bean section is a three-years rotation, the fungus is known to exist for such a period in the absence of the host plant. Observations indicate further that it may live for as long a period as ten years. In the laboratory, in soil to which no moisture was added, the pathogene died within a period of two years. In addition to water, decaying organic matter is no doubt necessary for the persistence of the pathogene in a saprophytic condition.

Only one experiment has been conducted which has any bearing on the length of time the pathogene may live in the soil under natural conditions. This experiment was begun in 1915 and data were taken at the end of three years. Four rows of beans, approximately 100 feet long, were inoculated with the fungus *F. martii phaseoli*. Four rows were planted as a check to determine whether the pathogene was already inhabiting the soil. The plants of the check rows remained healthy. At the end of the season the bean plants were cut off and the roots were allowed to remain in the soil. The plot was then dragged over and sown to wheat and clover, both red clover and alsike (*Trifolium pratense* and *T. hybridum*) being used in the seeding. After the wheat was cut in 1916, the clover remained on the plot until the spring of 1918, when the plot was planted to potatoes. In October of 1918 soil was taken from the plot where the diseased plants had been, and was placed in sixteen pots in the greenhouse. Three seeds of the Red Kidney variety of beans were placed in each pot. At the end of five weeks the roots of the plants were examined. In no case were lesions of the dry root-rot observed on them. The results of this experiment are contrary to all observations of the writer in the field. Moreover, the test is small and inconclusive, and is given here merely for what it is worth.

In just what form the pathogene persists during the winter and in the absence of its host plant has not been determined. It is probably in the mycelial stage during favorable conditions and in the chlamydospore stage during adverse conditions. Repeated examination of overwintered matter has never revealed the presence of a sexual stage.

PATHOGENICITY

Inoculation experiments with the bean plant

Many hundreds of inoculations have been made from time to time with *Fusarium martii phaseoli* on the roots of bean plants. In approximately one hundred per cent of the tests, infections occurred. These experiments were conducted both in the greenhouse and in experimental gardens. Infection takes place readily when the soil is contaminated before the seed is planted, when the seeds are dipped in suspensions of spores from a pure culture and planted in sterilized soil, and when inoculations are made with the pathogene after the plants are above ground. The incubation period under favorable conditions is about five days to a week. The spores used in these experiments were taken from pure cultures and always showed a high percentage of germination. The age of the cultures varied greatly; this factor, however, is unimportant, since the spores do not lose their viability very early.

Inoculation experiments were conducted to determine other important points respecting the pathogenicity of the fungus. The length of the period of susceptibility in the bean plant was thought to be worthy of consideration. It was believed that if it were found that infection takes place only in the seedling stage, a basis for controlling the disease would be available. It might be possible to protect the bean roots from the pathogene for a short time. On the other hand, the extermination of the fungus in the soil is exceedingly difficult without injury to the host plant or without too great expense. It was found, however, that the bean plants were susceptible over a greater period than the seedling stage. The results of the experiment to determine this point are set forth in table 1. The seeds used in the experiment were of the White Marrow variety.

The plants inoculated thirty-one days after planting became infected as readily as did those inoculated at the time of planting. From this it is evident that the period of infection does not extend over the seedling stage only, but on toward the maturity of the plant. It is possible that the plants are susceptible throughout their period of life. Early infection, however, would be more severe, as the fungus grows but slowly in the host.

TABLE 1. RESULTS OF AN EXPERIMENT TO DETERMINE THE PERIOD OF SUSCEPTIBILITY OF THE BEAN PLANT TO FUSARIUM MARTII PHASEOLI

Date of planting (1915)	Number of days until inoculation	Number of plants	Number of infections
July 14	None	33	33
July 30	Check	35	0
July 30	8 days	40	40
July 30	Check	40	0
July 30	16 days	40	39
July 30	Check	45	0
July 31	31 days	36	36
July 31	Check	36	0

An experiment was conducted to determine whether the pathogene can live over winter in the compost heap and be carried back to the land. For this experiment manure was procured from a sheep barn where bean straw had been fed. The experiment was run in duplicate, one plot being at Perry and one at Ithaca. It is frequently almost impossible in certain counties to obtain land free from this pathogene. Since Ithaca is out of the bean-growing district, it was more or less certain that the land there would not be contaminated with the fungus. The experimental plot at Perry was situated in the center of an old apple orchard and also proved to be free from the organism.

In each plot two rows of beans, of approximately 150 plants each, were used. In some instances the seed-corn maggot (*Phorbia fusciceps* Zett.) and the slug (*Agriolimax* sp.) destroyed a number of plants. One row

TABLE 2. RESULTS OF AN EXPERIMENT TO DETERMINE WHETHER FUSARIUM MARTII PHASEOLI MAY WINTER IN THE COMPOST HEAP AND BE CARRIED BACK TO THE LAND THE FOLLOWING SEASON

	Number of healthy plants	Number of diseased plants
Plots at Ithaca		
Treated row	47	40
Check row	147	2
Plots at Perry		
Treated row	38	107
Check row	96	3

was used as a check row, while the other was heavily fertilized with the bean-straw manure. The manure contained decaying pieces of bean stems and roots which had been in the compost heap during the preceding winter. The plots at Ithaca were planted on June 22, 1916, and those at Perry were planted on June 28, 1916. The results of the experiment are shown in table 2.

The few diseased plants appearing in the check rows can be accounted for readily as infections caused by washings from the diseased rows. The fungus also could have been transferred during cultivation.

Cross-inoculations

Many inoculation experiments were conducted to find other hosts of *Fusarium martii phaseoli*. These experiments were conducted both in the greenhouse and in the garden. In all cases rows of beans were inoculated with the pathogene as a check. Without exception infection was obtained on the bean. The following plants proved susceptible to *F. martii phaseoli*: the tepary bean (*Phaseolus acutifolius* Gray var. *latifolius* Freeman), the scarlet runner bean (*P. multiflorus* Willd.), the adzuki bean (*P. angularis* Willd.), the moth bean (*P. aconitifolius* Jacq.), the Black-eye cowpea (*Vigna sinensis* [L.] Endl.), and the kulti bean (*Dolichos biflorus* L.). Infection was very light on the scarlet runner and the lima bean.

Negative results were obtained with a number of legumes and other plants. This list is as follows: the garden pea (*Pisum sativum* L.); the field pea (*P. sativum* L. var. *arvense* Poir.); red clover (*Trifolium pratense* L.); alsike clover (*T. hybridum* L.); vetch (*Vicia* sp.); the following varieties of soybeans (*Soja max* Piper)— Medium Green, Ito San, Auburn, Wilson; corn (*Zea mays* L.); potato (*Solanum tuberosum* L.); oats (*Avena sativa* L.); wheat (*Triticum* sp.); and the following weeds —*Ambrosia artemisiifolia* L., *Prunella vulgaris* L., *Chenopodium album* L., *Rumex* sp. The weeds used in the inoculation experiments were those found commonly in the bean fields.

EFFECT OF WEATHER CONDITIONS

In the case of root parasites, infection is not so dependent on weather conditions as with those pathogenes which attack parts of plants above ground. Such factors as sun, wind, rain, and dews are eliminated.

Except under very prolonged drought there is sufficient moisture in the soil for spores to germinate and infect the host. Temperature appears to be the chief limiting factor, and from recent articles on the subject this varies greatly with the pathogene and the host. Gilman (1914 and 1916) considers high temperature favorable to infection of cabbage by *Fusarium conglutinans* Wr. Tisdale (1917 a) came to similar conclusions in his observations on the infection of flax by *Fusarium lini* Bolley, and states that from 15° to 16° C. is the minimum temperature at which infection will occur. Ramsey (1918), on the other hand, is of the opinion that a cool, moist soil is essential for infection by *Spongospora subterranea* (Wallr.) Johnson to occur on potato tubers.

In working with *Fusarium martii phaseoli*, the organism under consideration, Reddick (1917) found that infection occurred between temperatures of 15° and 34° C. His results have been substantiated by the writer. These temperatures include, with the exception of a few cases, the limits of the soil temperature found to exist at Perry, New York, during the growing seasons of 1916 and 1917. Records were taken at that place with a continuous self-recording soil thermograph. In no case was the temperature recorded higher than 30° C., and only a few times did it drop below 15° C.; in the latter instances it always rose immediately. From these data it is apparent that the soil temperature about Perry, which is near the center of the bean district, is always sufficient for the bean plant to become infected with *F. martii phaseoli.*

Besides the effect that soil temperature has on infection, there is also its effect on the progress of the disease after infection has once taken place. The latter is possibly of the greater importance. The problem here is more complex and very few definite conclusions have been drawn pertaining to it. Reddick, in the article cited above, has shown that soil temperature influences very greatly the growth of the bean plant. High temperatures allow much more rapid yet healthy growth than do low temperatures. Thus it is difficult to analyze data concerning the effect of the disease at different temperatures of the soil, since the rate of growth of the host plant varies so much. There were, however, in experiments conducted under these conditions, indications that the disease is more severe at a soil temperature of 22° C. than at 34° C. The former temperature is nearer the average of the soil temperature found in the bean district during the growing seasons of 1916 and 1917.

Even more marked than the effect of soil temperature on the disease is the effect of varying amounts of soil moisture. As already stated, the pathogene *F. martii phaseoli* is not a wilt-producing organism although the mycelium frequently invades the vascular system. The effect of the fungus is rather to kill and dry up the tissue as it progresses up the root, thus greatly reducing the root system of the plant. The roots that remain healthy or are able to carry on their normal functions are the surface roots. If there is an abundance of water in the soil, these surface roots can supply the plant with sufficient moisture. As the percentage of soil moisture decreases, however, this ability of the surface roots to supply moisture also decreases. A drought of ten days or two weeks will bring forth from the growers the statement that their beans are "going back." The expression is descriptive. The symptoms of the disease become very evident in a relatively short time. If a prolonged dry spell occurs at the time of blossoming and pod production, it is very injurious to the diseased plants. The yield, without doubt, will be reduced over fifty per cent. On the other hand, a very high moisture content of the soil aids materially in the dissemination of the fungus. Moisture also causes a more rapid progress of the disease in the host, since the diseased parts, which are usually dry, absorb water very readily. In this way sufficient moisture is supplied to the pathogene. A continuous rainy season, however, does not cause a noticeable reduction in yield of diseased plants. During the season of 1915 a field of White Marrow beans near Wyoming, New York, was under the observation of the writer. The plants on this field were severely infected, and at podding time fifty per cent or more of their root system was destroyed. Nevertheless a yield of 24 bushels to the acre was produced. Unquestionably this was due to the fact that the surface roots, which are more numerous in damp than in dry soil, were able to supply the plant with water. During the dry season of 1916 the writer observed numerous bean fields affected with the dry root-rot which did not produce over two or three pods to a plant. In this season there was sufficient moisture directly after planting time to cause a succulent growth in the plant and a rapid progress of the disease. Throughout the dry period that followed, the plants were checked in their growth and few pods were formed.

EFFECT OF DRY ROOT-ROT ON THE YIELD OF THE BEAN CROP

Few experiments have been conducted to determine the exact effect of any plant disease on the yield of its host. For a crop that is subject to numerous diseases, such information is frequently of extreme value. This is true of the bean, in the case of which several pathogenes may occur on the roots of the plants. One of these is the dry root-rot, and, since inoculations can be controlled, an experiment to learn the effect of this disease on the bean crop can readily be conducted.

Since the black root-rot is so frequently associated with the dry root-rot, it was considered advisable to determine the loss in yield resulting from each as well as from a combination of the two diseases. For the sake of accuracy such an experiment should be repeated through several seasons in order to avoid the effect of unusual weather conditions. A preliminary experiment of this type was conducted in 1916. The seed was not planted until July 20, and therefore the crop did not mature before the early frost of that season. Plants in the rows inoculated with *Fusarium martii phaseoli* were considerably dwarfed, but those inoculated with *Thielavia basicola* could not be distinguished from the check rows. A combination of the two, from all appearance, caused no more injury than did *F. martii phaseoli* alone. It was unfortunate that the beans could not be harvested, inasmuch as the weather was especially favorable for the effects of the disease to appear in the yield.

In 1917 a more extensive experiment was conducted at Ithaca. The weather conditions were very unfavorable for the dry root-rot, but were advantageous for the bean plant. Marked losses, therefore, which would be noted in average years or in years favorable for the disease, were not obtained. Some interesting facts appeared in the experiment, and for this reason the data, although incomplete, are set forth here.

The plot at Ithaca used for the experiment was located on a low piece of ground. The soil was a gravelly loam. In previous years the plot had been in alfalfa, and no records show that it had ever been planted to beans. It was likewise out of the bean area and the soil proved to be free from the pathogene *Fusarium martii phaseoli*. The soil was likewise free from *Thielavia basicola*, since all checks remained healthy even though this organism is widely distributed and occurs on such hosts as alfalfa.

The plan of the experiment was as follows: Plants in row 1 were inoculated with *Thielavia basicola*; row 2 remained as a check; row 3

was inoculated with *T. basicola* and *Fusarium martii phaseoli*; row 4 was a check; row 5 was inoculated with *F. martii phaseoli*; row 6 was a check. The rows were three feet apart and one hundred feet long. They were repeated five times. To eliminate outside rows, buffer rows were planted on either side of the plot.

The seed, which was a Marrow Pea variety, was planted on June 14. Rain had fallen on the preceding day and the soil contained sufficient moisture to keep the spores of the fungi from being killed by drying. The same quantity of seed was used for each row, and all seeds were inoculated with the legume bacteria before planting. The check rows were covered before the others were inoculated, to avoid any danger of contamination.

During the summer the plot was cultivated twice and weeded, but it was not hoed. Thus there was little danger of the fungi's spreading from the infected rows to the check rows. When the plants were pulled in the fall no infection was found to have occurred on the check plants.

Since the season was wet and the plots were located in the low ground, plenty of moisture was retained in the soil. After June 14 rain fell on the following dates: June 15, 18, 19, 20, 23, 26, 27, 28, and 29 — a total precipitation of 3.89 inches. During July rain fell on the following dates: July 1, 2, 3, 4, 6, 8, 9, 10, 11, 12, 13, 14, 15, 17, 18, 19, 20, 21, 26, and 29 — a total precipitation of 3.25 inches. In the month of August rain fell on the following days: August 2, 3, 6, 8, 9, 10, 13, 14, 15, 16, 22, 23, 28, 29, and 30 — a total precipitation of 8.45 inches. In the first half of September there was precipitation on the 1st, 2d, 6th, 7th, 8th, 9th, and 10th, with a total of 1.41 inches. Thus it may be seen that the soil was in a moist condition throughout the summer, especially during the critical month of August when the pods are produced. The plants grew rapidly and soon covered the ground. The majority produced a large number of pods, and from the general appearance the inoculated rows could not be distinguished from the check rows.

When the plants were pulled in the fall, considerable injury was observed on the roots of the plants inoculated with the dry root-rot fungus. In many cases all that remained of the roots was a dried stub, but the parts above ground were apparently healthy. The rows affected with the black root-rot showed more injury than during the dry, hot summer of 1916. Few plants, however, showed serious injury. Those

inoculated with both the fungi could not be separated from those inoculated with *Fusarium martii phaseoli* alone. As to the yield in the different rows, nothing could be determined from observation. Each row was harvested and threshed separately and the amount of seed was weighed. The data are given in table 3.

TABLE 3. EFFECT OF ROOT DISEASES ON THE YIELD OF THE BEAN DURING THE SEASON OF 1917

Row	Inoculation	Weight of seed (grams)	Reduced or increased yield (per cent)*
	Buffer row		
1	Black root-rot	3,585	72.6
2	Check	4,938	
3	Dry root-rot Black root-rot	3,749	76.4
4	Check	4,877	
5	Dry root-rot	4,743	105.9
6	Check	4,083	
7	Black root-rot	4,843	107.4
8	Check	4,933	
9	Dry root-rot Black root-rot	3,538	72.9
10	Check	4,778	
11	Dry root-rot	3,751	81.0
12	Check	4,483	
13	Black root-rot	4,722	100.5
14	Check	4,916	
15	Dry root-rot Black root-rot	3,759	75.8
16	Check	5,006	
17	Dry root-rot	4,781	96.3
18	Check	4,922	
19	Black root-rot	4,565	101.1
20	Check	4,111	
21	Dry root-rot Black root-rot	3,915	92.6
22	Check	4,345	
23	Dry root-rot	4,242	105.0
24	Check	3,738	
25	Black root-rot	2,421	58.0
26	Check	4,604	
27	Dry root-rot Black root-rot	2,810	65.0
28	Check	4,041	
29	Dry root-rot	3,394	82.7
30	Check	4,162	
	Buffer row		

* The reduced or increased yield is calculated by determining the percentage of yield of the diseased row in relation to the average of the yields of the two adjacent check rows.

In studying this table several points should be taken into consideration which have or might have a disturbing effect on a proper interpretation of the data. In all instances these points deal with individual rows. Since the first row served as a buffer, the yield was not determined, and hence the check percentage of row 1 was calculated from only one check row. In all other cases the average of the check rows on both sides of the diseased row was used. In check row 6 it may be seen that the yield was far below the normal. The cause of this is unknown. It resulted, however, in unfair calculated check percentages for rows 5 and 7. If rows 4 and 8 only had been used, the check percentages would not have been above one hundred. Row 25, which shows a very low yield and therefore a low check percentage, had a small number of plants. Row 27 also had a small number of plants, but this was not evident on the yield. The writer appreciates the fact that rows of equal length may have varying numbers of plants without affecting the yield of these rows. For this reason it is considered best to use rows in an experiment of this type instead of a certain number of plants. Just how much thinning a row may permit before a noticeable decrease in yield occurs is not known.

In consideration of these disturbing factors, very few data are presented which show that the black root-rot reduces the yield of beans to any extent. The weather, no doubt, was as favorable as possible for this disease and the root-rot approached its maximum in severity. The injury from the black root-rot was brought about to a large extent by the destruction of the plants in the seedling stage. The remaining plants, therefore, had a better opportunity to develop and offset this injury. The calculated check percentages for the dry root-rot on the whole are high. This is to be expected, however, when the soil retains a large amount of moisture throughout the growing season. With the combination of the diseases there appears to be a consistent reduction in the yield.

A further experiment to determine the effect of the dry root-rot on the yield of the bean was conducted during the season of 1918. The plot of land selected, although not so advantageous for beans, was located on higher ground than that used in the experiment of 1917. The soil contained a considerable amount of clay. The plan of the experiment was the same as in 1917 with the exception that only the fungus *Fusarium*

martii phaseoli was used. Six rows were inoculated, with a check row left between each two treated rows. All seed used in the experiment was inoculated with the root-nodule organism.

During the summer the plot was cultivated twice and weeded. At podding time a slight difference could be distinguished between the check rows and the rows of infected plants. That this should occur in 1918 and not in 1917 was due to the lower ground on which the plot was located in 1917 and to the general raininess and cloudiness of that growing season. The plot was planted on June 4, after which rain fell on the following dates: June 6, 7, 10, 11, 12, 13, 14, 21, 22, 23, 25, 28, and 29 — a total precipitation of 3.05 inches. Thus a sufficient amount of soil moisture was present during the infection period. In July rain fell on the following dates: July 1, 3, 5, 9, 10, 11, 17, 24, 29, and 30 — a total precipitation of 4.55 inches. During August, when the pods are formed, there was less than half as much precipitation as in the month of August, 1917; rain fell on the following dates: August 4, 5, 8, 10, 14, 24, 26, 28, 29, and 30 — a total precipitation of 3.76 inches. The plants were harvested in the first part of September. The results of this experiment are shown in table 4:

TABLE 4. EFFECT OF THE DRY ROOT-ROT ON THE YIELD OF THE BEAN DURING THE SEASON OF 1918

Row	Inoculation	Weight of seed (grams)	Reduced yield (per cent)*
1	Check	291	
2	Dry root-rot	548	61.9
3	Check	1,478	
4	Dry root-rot	723	47.9
5	Check	1,538	
6	Dry root-rot	954	56.3
7	Check	1,848	
8	Dry root-rot	709	43.8
9	Check	1,392	
10	Dry root-rot	720	61.7
11	Check	941	
12	Dry root-rot	484	51.4

* The reduced yield was calculated as in table 3 (page 1024).

The experimental plot used in 1918 was an apparently level piece of ground, nevertheless it may be seen that the yield near the center was

much higher than that on either side. However, observation in most bean fields will show that the outside rows are composed of low-yielding plants. In other respects the data for this experiment are not difficult to analyze. Weather conditions were such as to make the effect of the dry root-rot very noticeable. The decrease in yield in diseased rows averages approximately fifty per cent.

CONTROL

ROTATION OF CROPS

Since the cause of the dry root-rot is a soil pathogene, the possibility of controlling the disease through longer crop rotations was considered very early in these investigations. The common rotation practiced by the growers of dry shell beans is but three years, and frequent instances are found in which the rotation is only two years. It is customary to follow beans with wheat and then clover, although in the fruit-growing districts this rotation may vary somewhat. In all localities, however, a few growers vary their rotations considerably. For this reason a survey was made in Wyoming County in 1915, and in Genesee, Livingston, and Monroe Counties in 1916, to determine whether these variations in rotation affect the disease to any extent. Very little information was obtained. Fields were observed in which beans had not been grown for ten years and yet the dry root-rot was present. In some of these fields the pathogene might have been continuously returned to the soil in the manure. On the other hand, this explanation could scarcely hold for pasture land.

One point drawn from the survey that should be noted is, the shorter the rotation the more serious is the disease, although long rotations do not eradicate the fungus. From this it appears that the pathogene will accumulate more rapidly in the presence of the bean plant. Nevertheless it still persists in the absence of this host plant, and, as far as is known, no other crop grown in rotation with the bean and no weeds found commonly in the fields are susceptible to its attacks. It would thus appear that the fungus lives saprophytically in the soil. It is not uncommon for pathogenic members of the genus Fusarium to do this, since they frequently have been isolated from the soil in the absence of their host plant. Pratt (1918) isolated *Fusarium radicola* Wollenw. and *F. trichothecioides* Wollenw., two potato pathogenes, from virgin soil in Idaho.

From the foregoing observations on the character of *Fusarium martii phaseoli*, it appears highly improbable that the dry root-rot of beans can be entirely eliminated by longer crop rotations.

SOIL TREATMENT

The application of chemicals and fertilizers to the soil to destroy or hold in check soil pathogenes, has seldom proved successful on an extensive scale. In seedbeds and greenhouses where expense does not prohibit, treatment with formaldehyde may be used profitably. A formaldehyde solution applied in the furrow with the seed at the time of sowing has proved effective in the control of onion smut. On the other hand, the application of fertilizers has tended at times to lessen the effect of certain root diseases. Such has been the case in liming fields contaminated with the organism causing clubroot of cabbage. Acid phosphate applied to tobacco fields also has proved to be beneficial in holding in check the black root-rot.

During the season of 1915 a number of farmers near Perry and Warsaw, New York, under the direction of the Wyoming County Farm Bureau tried varying applications of lime and acid phosphate on their bean fields. Four of the farms were visited by the writer with H. M. Bowen, the County Agent, and careful observations were made. In no instance could it be determined that the fertilizers checked the disease to any extent. Similar reports were received from various other farms.

The application of toxic substances to the soil, especially non-volatile substances, must be made with great care. The roots of the plants are extremely sensitive and in the seedling stage great injury may be done to them. The pathogene, too, s frequently very resistant to chemicals and cannot be destroyed easily. Furthermore the after effects of treatment with various chemicals have been reported to be injurious to other crops grown in rotation. Sherbakoff (1915 a) has shown this to be true for clover when sulfur was applied previously; and Wheeler, Hartwell, and Moore (1899) have shown the same thing to be true for cereals.

However, regardless of the fact that clover generally occurs in the rotation with beans, a preliminary test was made with sulfur in the summer of 1915. Sulfur was drilled in with the seed at the rates of 200 pounds and 400 pounds to the acre. In neither case was the germina-

tion of the seed injured, but over 95 per cent of the plants showed severe infections of the dry root-rot. Later in the summer these rows were torn up and again planted to beans. It was thought that by that time the sulfur might have had an effect on the pathogene. Practically all the plants became infected. No further experiments with sulfur were conducted.

A volatile chemical which would kill the pathogene and then evaporate would be the ideal substance to apply. The use of formaldehyde possibly furnishes the closest approach to this condition. Calcium hypochlorite is another substance which would break down and leave no injurious substances. In the winter of 1915–16 preliminary tests were conducted with these two substances. One of the beds in the greenhouse was thoroughly contaminated with *Fusarium martii phaseoli*. It was then divided into three plots, each containing 12 square feet, and planted to beans. Plot 1 was treated with calcium hypochlorite applied at the rate of 200 pounds to the acre and drilled in with the seed; plot 2 was left as a check; plot 3 was treated with a formaldehyde drip similar to that used in onion smut treatment. The strength of the formaldehyde solution used was 1:100 and it was applied at the rate of 400 gallons to the acre. The germination of the seed was not injured by the formaldehyde, but injury to the extent of 75 per cent was observed on the plot treated with calcium hypochlorite. In both plots all plants were as severely infected as those in the check plot.

Further experiments with calcium hypochlorite and formaldehyde were conducted in the field in the season of 1916. A bean field near Perry, known to be contaminated with *F. martii phaseoli*, was used for the purpose. In each plot the beans were planted in four rows 28 inches apart, each row containing about 100 plants. Some of these were destroyed by the seed-corn maggot and by slugs. Plot 1 was treated with calcium hypochlorite at the rate of 200 pounds to the acre, the treatment being made ten days before planting; plot 2 was treated with the same substance at the rate of 100 pounds to the acre, and the chemical was drilled in at the time of planting; plot 3 was treated with formaldehyde, 1:100, which was applied as a drip at the time of planting at the rate of 400 gallons to the acre (this plot was repeated three times); in plot 4 the strength of the formaldehyde was doubled. Only in the last plot was any injury to the germination of the seed observed. No beneficial effects

were noted. In all plots, including the check, the proportion of healthy plants did not exceed 5 per cent.

Similar experiments were conducted in 1918 with the commercial preparation cyanamid. Three plots, each 20 feet long and 12 feet wide, were treated with varying amounts of the chemical, and a plot of similar size was used as a check. Plot 1 was treated at the rate of 50 pounds to the acre, plot 2 at 75 pounds to the acre, and plot 3 at 100 pounds to the acre. The applications were made at the time of planting, which was August 10, and the chemical was drilled in the rows. The variety of beans used was Well's Red Kidney. This method of treatment injured the germination considerably and retarded the growth of the plants to a severe extent. The experimental plots were examined on October 3. Over 90 per cent of the plants in the treated plots showed severe infection of the dry root-rot. No distinction could be made between these and the plants in the check plot. The results do not warrant further experiments with cyanamid.

USE OF BEANS RESISTANT TO ROOT-ROT

Very little progress has been made in controlling plant diseases caused by soil-inhabiting fungi, except by the selection and development of disease-resistant strains. This is especially true when the pathogene concerned belongs to the genus Fusarium. Orton (1908) has used this method in checking the wilt of cotton, cowpea, and watermelon. Bolley (1903), and more recently Tisdale (1917b), have selected wilt-resistant varieties of flax. Jones and Gilman (1915) have employed the method with great success in controlling the yellows of cabbage. Norton (1914) and Edgerton (1918) have selected tomatoes resistant to the Fusarium wilt.

In New York State, fields of the White Marrow bean are frequently lacking in uniformity of type of the bean. Among the varying types is a strain to which, for convenience, the name *Flat Marrow* has been given by the writer. During the summer of 1915 it was observed that this strain exhibited a high degree of resistance to the dry root-rot.

In character the Flat Marrow varies somewhat, from a true White Marrow to a Burlingame (or Medium, as it is commonly called in New York State). The plant has a compact form of growth with broad and dark green leaves. The stems are heavier than in the common Marrow. The shape of the pod is that of a Medium, while frequent dashes of blue

lead to the belief that the strain is closely related to the Blue Pod Medium. The seeds are smaller and flatter than in the Marrow, but seldom are they the shape of those of the Burlingame. During the early part of the season these plants are difficult to distinguish from the Marrow, but a few weeks before harvest time they may readily be distinguished from the other varieties. This is due practically to the fact that the resistance to root-rot is remarkably noticeable (Plate LVI, 3). The Flat Marrow cannot be grown commercially in New York State, however, because of several objectionable characters. It is later than the White Marrow and, altho very productive, it frequently is injured by frosts. Another undesirable character is the length of its podding season. When the first pods are ripe the later ones are still small and green. Nevertheless its character of resistance to root-rot makes it a valuable bean.

It has been shown by the writer (1918) that resistance to anthracnose in beans can be transferred from one variety to another by hybridization. It was therefore hoped that by crossing the Flat Marrow with any of the common commercial varieties of bean, strains of the latter might be obtained resistant to the dry root-rot. In making selections among the Flat Marrow for parent stock, other characteristics besides disease resistance were considered. These were, earliness of maturing, and tendencies toward a White Marrow or a Medium type of bean. In 1915 only nineteen individuals were selected. The progeny of these were tested for resistance in the greenhouse during the following winter and in the field during the seasons of 1916 and 1917. Only seven strains were discarded. Numerous crosses have been made by the writer between the Flat Marrow and the White Marrow, and more recently E. W. Lindstrom and G. P. McRostie have hybridized the resistant type with a number of other commercial varieties of dry shell beans. The F_2 generation of all the first hybrids have been grown, and part of the F_3 generation. These have exhibited a very complex segregation, and it is the opinion of the writer that the character of disease resistance in this case is not governed by simple factors.

As yet no White Marrow strain has been isolated resistant to the dry root-rot. Insufficient knowledge concerning the genetical behavior of the characters of resistance to this disease, however, renders it impossible to state with certainty what may be done. Nevertheless it is hoped that desirable types possessing root-rot resistance may be obtained from the above crosses.

LITERATURE CITED

APPEL, O., AND WOLLENWEBER, H. W. Grundlagen einer Monographie der Gattung Fusarium (Link). K. Biol. Anst. Land- und Forstw. Arb. **8**: 1–207. 1913.

BOLLEY, H. L. Flax and flax seed selection. North Dakota Agr. Exp. Sta. Bul. 55: 171–198. 1903.

BURKHOLDER, W. H. Some root diseases of the bean. (Abstract.) Phytopath. **6**: 104. 1916.

——— Bean diseases in New York State in 1916. (Abstract.) Phytopath. **7**: 61. 1917.

——— The production of an anthracnose-resistant White Marrow bean. Phytopath. **8**: 353–359. 1918.

CARPENTER, C. W. Some potato tuber-rots caused by species of Fusarium. Journ. agr. res. **5**: 183–209. 1915.

EDGERTON, C. W. A study of wilt resistance in the seed-bed. Phytopath. **8**: 5–14. 1918.

GILMAN, J. C. The relation of temperature to the infection of cabbage by Fusarium conglutinans Wollenw. (Abstract.) Phytopath. **4**: 404. 1914.

——— Cabbage yellows and the relation of temperature to its occurrence. Missouri Bot. Gard. Ann. **3**: 25–84. 1916.

JONES, L. R., AND GILMAN, J. C. The control of cabbage yellows through disease resistance. Univ. Wisconsin Agr. Exp. Sta. Res. bul. 38: 1–70. 1915.

NORTON, J. B. S. Tomato diseases. *In* Maryland Agr. Exp. Sta., Bul. 180: 102–114. 1914.

ORTON, W. A. On the theory and practice of breeding disease-resistant plants. Amer. Breed. Assoc. **4**: 144–156. 1908.

PRATT, O. A. Soil fungi in relation to diseases of the irish potato in southern Idaho. Journ. agr. res. **13**: 73–99. 1918.

RAMSEY, G. B. Influence of moisture and temperature upon infection by Spongospora subterranea. Phytopath. **8**: 29–31. 1918.

REDDICK, DONALD. Effect of soil temperature on the growth of bean plants and on their susceptibility to a root parasite. Amer. journ. bot. 4:513–519. 1917.

SHERBAKOFF, C. D. The after effect of sulfur treatment on soil. Phytopath. 5:219–222. 1915 a.

——— Fusaria of potatoes. New York (Cornell) Agr. Exp. Sta. Mem. 6:85–270. 1915 b.

TISDALE, W. H. Relation of temperature to the growth and infecting power of Fusarium Lini. Phytopath. 7:356–360. 1917 a.

——— Flaxwilt: a study of the nature and inheritance of wilt resistance. Journ. agr. res. 11:573–605. 1917 b.

WHEELER, H. J., HARTWELL, B. L., AND MOORE, N. L. C. Upon the after effect of sulfur, when applied to soils for the purpose of preventing potato-scab. Rhode Island Agr. Exp. Sta. Ann. rept. 12:163–167. 1899.